HUMIDITY IN RELATION TO MOISTURE IMBIBITION BY WOOD AND TO SPORE GERMINATION ON WOOD

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Introduction

In a previous publication the writer ('16) pointed out that between a certain minimum and maximum of moisture in wood *Lenzites saepiaria* and other similar wood-destroying fungi will grow and cause the destruction of the wood. Thus, the power of wood to absorb moisture, whether as vapor from the air or as water from objects in contact with the wood, is a factor of prime importance in its susceptibility to decay. It is no less true that any property of the wood which may influence its moisture-absorbing capacity is a factor in its durability. In this connection it has been suggested (Zeller, '16) that, although resin has no actual toxic effect on the growth of wood-destroying fungi, it does inhibit growth when in large percentages and its only inhibitive power probably lies in the fact that it excludes water from the fibre containing it (Zeller, '17).

With these previous results as a foundation further investigations have been conducted to ascertain (1) the amount of moisture which wood will absorb from the atmosphere at different relative humidities when the temperature remains constant; (2) whether the water-proofing effect of resin on wood can be measured; and (3) the relation of the moisture content of wood (or relative humidity of the atmosphere) to the propagation of wood-destroying fungi on wood. The purpose of the present paper is to report the results of these experiments.

Experimentation

Materials used.—For the experiments reported below samples were selected from specimens of shortleaf pine (*Pinus echinata*) secured at the Fordyce Lumber Company, Fordyce, Arkansas, and from specimens of longleaf pine (*Pinus palustris*) secured at the

Calciseau Lumber Company, Lake Charles, Louisiana. From these samples approximately 250 specimens of each species were selected, so that a wide range in resin content and specific gravity as well as sap- and heart-wood might be represented.

The samples were allowed to air-dry for several weeks in a room at about 50 per cent relative humidity. They were then measured for volume and weighed, and the specific gravity determined for the whole sample. The samples were usually 2×6×48 inches. Of course, these specific gravities are not standard (Newlin and Wilson, '19), for the specimens were not *oven-dry* when weighed. Since the samples were obtained for the purpose of measuring the moisture-absorbing power of the wood they were not kiln-dried, for this tends to reduce the hygroscopic property of the wood below that obtaining in green samples (Tiemann, '07). This point was kindly called to my attention by C. H. Teesdale of the Forest Products Laboratory, Madison, Wisconsin, and in a report from that laboratory on "Wood in aircraft construction" (1919) the relation of kiln-drying of wood to its hygroscopicity is quite generally discussed. All samples finally selected for the moisture-absorption tests were marked and so labeled that after they were cut into blocks 2×2×4 inches, each block could be identified as to which sample it belonged and as to its position in the sample. From these small blocks uniformly clear pieces were selected for the preparation of shavings which were uniform in thickness. A preliminary experiment revealed the fact that the moisture-imbibing power of wood is not changed by shaving, but that imbibition is more rapid than when blocks were used. Therefore, in the experiments reported below shavings were used. The clear pieces selected were of a light color and had a resin content well below 5 per cent, except those otherwise designated in tables II and IV.

Description of humidors.—In order to determine the relation between the humidity gradient of the atmosphere and the moisture content of wood a closed chamber, or humidor, was devised so that a constant temperature would be maintained, and so that the humidity could be regulated either by different concentrations of sulphuric acid in trays enclosed in the chamber, by varying the evaporating surface of water in trays, or by hanging baskets of calcium chloride in the chamber. To pro-

duce the higher humidities, curtains of absorbent paper were hung in the chamber so that the lower portions were in contact with water in trays. This increase in evaporating surface proved very effective.

The humidor with apparatus complete as we used it is shown in plate 1. The humidor proper consists of two double-walled boxes, one within the other, built of spruce lumber. The double walls are packed with sawdust for insulation against temperature changes. For added insulation there is an air space separating the inner and outer box. The inner box, which is the chamber proper, has a double-walled door provided with a double-glass window, through which temperature and dew-point observations can be made without opening. The outer door is double-walled and packed with sawdust. The doors are provided with ordinary cold-storage catches. There are three one-inch openings, one through the top and one through each end. The inner walls of the humidor chambers were water-proofed in two ways: (1) Those of two humidors were brushed with hot paraffin (parawax) and were then thoroughly ironed with a hot electric iron. Further applications of the paraffin were made in the same manner. (2) The walls of two other humidors were primed and painted with several coats of a water-proof enamel and valspar. The paraffin treatment does not give as good an appearance as the enamel paints, but it proved to be the better water-proofing agent.

The temperature of the chamber was maintained at 25° C. by means of a bimetallic thermo-regulator in circuit with an electric light as a heating element.

Determination of relative humidity.—There was no difficulty in maintaining a constant relative humidity throughout any one experiment. The relative humidity of the chamber was determined by means of a Milliken dew-point apparatus, which consists of a highly polished, nickel, cylindrical cup provided with a three-hole stopper. One of these holes supports a thermometer and the other two provide an intake and outlet for the siphoning of water or freezing mixtures through the cup. This apparatus shows plainly in fig. 2, pl. 1. The dew-point is determined by the appearance and disappearance of the film of moisture on the polished cup as the temperature is changed by

allowing water to flow through the siphon. From the vapor pressures of the dew-point and the temperature of the chamber the relative humidity is obtained. The pressure of aqueous vapor at various temperatures was secured by recourse to the Smithsonian physical tables (Fowle, '10).

Method of weighing within the humidor.—The samples of wood shavings which were used to measure the imbibition of moisture from the atmosphere were planed as needed and placed in the wire baskets shown in fig. 1 and 2 of pl. 1. The baskets provided with hooks were hung on two wires which were stretched across the chamber, one on either side of the openings in the top and the right-hand side of the chamber. Balances were installed on the top of the humidor in such a position that a wire supporting a counterweight passed down through the opening leading to the chamber. The lower end of this wire is hooked so that the wire baskets can be hung upon the balance by means of a lever which passed into the opening in the right-hand end of the humidor. This operation can be performed without opening the chamber and thus changing the temperature and humidity within. The wire lever and the counterbalance wire are each provided with a cork, which can be slipped back when the device is in use or into the apertures when not in use. This device is an adaptation of that described by Dixon ('98).

A similar one to that described by the writer has been used for the same purpose by Mr. C. H. Teesdale in charge of the Section of Wood Preservation at the Forest Products Laboratory, Madison.

Determination of moisture content of wood.—After the samples of shavings had come to a constant weight in the humidor they were weighed and at the same time the relative humidity of the chamber was determined and recorded. The samples were then dried to constant weight in a dry-air oven at 100–105° C. The difference between the weight taken in the chamber and that after drying gave the total amount of moisture in the samples including that absorbed at the relative humidity of the chamber. The per cent of moisture absorbed was based on the oven-dry weight of the shavings.

Determination of resin content of wood.—To determine whether the influence of a high resin content on moisture absorption can

be measured experimentally samples were chosen and analyzed by the method previously reported (Zeller, '17).

Results of Experiments on Moisture Absorption

The data from the experiments to show the relation between the relative humidity of the atmosphere and the moisture content both of sap- and heart-wood of shortleaf and longleaf pine are given in tables I, II, III, and IV.

From the data recorded in these four tables (I, II, III, and IV), the humidity-moisture curves shown in figs. 1, 2, 3, and 4, respectively, were plotted. These curves represent the ultimate moisture content at a given temperature and relative humidity of the surrounding atmosphere. The samples used in each experiment were of three distinct specific gravities chosen to represent the approximate average specific gravity of the species of wood, as well as densities both heavier and lighter than the average. In the case of heart-wood, however, an extra series of samples was used. These were highly resinous and consequently very dense. Other than these highly resinous pieces, the samples had a resin content well below 5 per cent.

The four curves are strikingly similar. In all cases where the samples of wood represented have specific gravities lying between .41 and .75 to .80 and small percentages of resin, the general curve for the moisture absorbed is followed up to a certain relative humidity where the percentage of moisture taken up by the wood of the three densities begins to vary according to the density. The lighter, or less dense, samples, from this point, take up more moisture with increased atmospheric humidity than do the denser samples. This occurs at a relative humidity averaging from 94.75 to 96 per cent. There seems to be but one explanation for a divergence of the curves at this juncture. Up to this point the wood fibre has not received enough moisture from the atmospheric humidity to satisfy its imbibition capacity, but beyond this point this hydration capacity is over-satisfied and the moisture over and above that absorbed by the fibre is adsorbed by the surfaces exposed. If this theory is correct the point of divergence of the three moisture-humidity curves represents the fibre-saturation point. As an irreversible colloid, wood is undoubtedly limited in further

TABLE I

PERCENTAGE MOISTURE CONTENT OF SHORTLEAF PINE SAP-WOOD SHAVINGS AT VARIOUS ATMOSPHERIC HUMIDITIES AND AT 25° C.

Samples of .41 specific gravity		Samples of .61 specific gravity		Samples of .69 specific gravity	
I	II	III	IV	V	VI
Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)
4.12	11.0	2.5	6.6	3.0	7.5
5.50	19.5	6.62	24.8	4.87	15.25
7.25	28.0	7.5	31.8	6.12	22.75
7.80	33.2	7.9	35.8	7.88	34.6
8.70	45.5	8.4	40.4	8.70	42.5
9.00	49.5	9.2	47.5	9.7	53.
9.88	53.8	9.5	54.5	10.75	62.5
10.62	58.8	10.3	58.8	11.6	66.0
10.80	60.4	10.4	61.3	12.6	69.5
11.12	63.8	11.5	65.0	14.25	76.8
12.80	68.8	12.2	67.5	15.3	79.3
13.88	73.8	13.0	71.8	16.3	84.4
15.5	81.0	16.2	82.2	19.3	91.0
17.25	86.5	17.6	86.4	23.4	95.3
18.5	87.8	20.0	90.0	24.5	96.5
18.75	90.0	21.6	93.2	25.0	97.5
21.4	92.25	24.25	96.0	26.0	98.2
22.3	94.4	26.0	97.4	26.25	98.8
23.8	95.5	26.6	98.2	27.1	99.3
25.4	96.6	27.12	98.2	27.75	99.5
27.6	97.5	27.6	98.7	28.0	100.0
28.9	98.4	28.6	99.2		
30.25	98.7	29.0	99.5		
31.5	99.2	29.88	100.0		
32.0	99.5				
34.0	100.0				

TABLE II

PERCENTAGE MOISTURE CONTENT OF SHORTLEAF PINE HEART-WOOD SHAVINGS AT VARIOUS ATMOSPHERIC HUMIDITIES AND AT 25° C.

Samples of .49 specific gravity		Samples of .61 specific gravity		Samples of .70 specific gravity		Resinous samples of .82–.90 specific gravity		
I	II	III	IV	V	VI	VII	VIII	IX
Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Per cent resin
3.8	10.3	3.2	8.0	3.875	9.4	6.62	24.8	15.6
4.75	13.6	6.2	20.4	5.12	15.6	7.9	33.6	16.2
6.5	23.2	7.0	26.2	6.00	19.0	8.5	38.5	16.7
7.2	30.2	7.6	31.8	7.12	27.8	9.32	43.5	16.2
7.5	33.2	7.7	34.6	7.5	30.3	10.2	49.6	15.6
9.0	41.5	8.4	36.	8.4	37.2	10.34	54.4	18.2
10.7	51.8	8.7	40.4	9.8	45.6	11.32	57.4	17.6
12.3	61.0	10.1	44.2	11.38	55.8	12.3	63.0	17.6
14.5	71.0	10.2	47.4	13.18	65.8	13.7	70.0	16.7
16.7	78.0	11.2	53.8	15.86	75.6	13.88	72.6	18.2
18.0	82.4	11.8	59.3	16.4	79.2	14.8	75.6	15.6
19.7	87.5	13.12	63.2	17.37	80.4	16.0	80.4	18.2
21.75	92.0	12.75	65.0	18.62	86.0	16.28	83.2	15.6
23.3	94.5	13.6	67.5	20.7	90.0	17.5	86.0	16.2
24.0	95.0	15.6	72.8	22.12	93.0	18.25	88.2	16.2
25.5	96.0	16.14	76.6	22.75	94.0	18.7	90.6	15.6
28.8	97.8	17.3	78.8	24.25	95.60	19.5	91.4	18.2
30.7	98.4	18.4	84.4	25.2	97.0	20.11	94.4	17.6
32.55	98.8	19.4	85.3	28.08	100.0	20.52	96.2	18.2
36.25	100.0	19.7	88.6			21.4	96.6	18.2
		20.3	88.8			21.41	98.6	17.6

TABLE II—*Continued*

PERCENTAGE MOISTURE CONTENT OF SHORTLEAF PINE HEART-WOOD SHAVINGS AT VARIOUS ATMOSPHERIC HUMIDITIES AND AT 25° C.

Samples of .49 specific gravity		Samples of .61 specific gravity		Samples of .70 specific gravity		Resinous samples of .82–.90 specific gravity		
I	II	III	IV	V	VI	VII	VIII	IX
Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Per cent resin
		21.2	91.			22.25	100.0	17.6
		22.6	93.2					
		24.75	96.2					
		25.75	97.0					
		27.12	98.0					
		29.32	98.8					
		31.25	99.4					
		33.10	100.0					

TABLE III

PERCENTAGE MOISTURE CONTENT OF LONGLEAF PINE SAP-WOOD SHAVINGS AT VARIOUS ATMOSPHERIC HUMIDITIES AND AT 25° C.

Samples of .41–.42 specific gravity		Samples of .70 specific gravity		Samples of .75–.80 specific gravity	
I	II	III	IV	V	VI
Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)
3.88	9.3	4.64	12.3	5.4	15.8
6.78	28.10	6.24	21.4	6.89	26.1
8.24	37.4	7.21	28.2	7.88	34.0
9.52	47.8	7.30	31.4	8.64	40.6
10.83	56.4	9.21	44.7	9.78	50.8
12.2	64.2	10.11	49.4	10.68	55.1
13.77	71.6	10.38	53.6	11.27	61.2
14.82	75.8	11.50	58.6	12.77	67.3
17.59	83.7	12.54	65.8	15.73	79.0
20.31	88.2	13.42	69.3	19.32	87.2
22.38	92.5	14.15	73.8	21.71	91.2
24.14	94.6	16.51	80.3	23.58	94.6
24.88	95.4	17.07	82.5	23.96	95.4
25.76	96.2	18.48	85.5	24.54	96.1
26.63	96.7	20.74	89.7	24.74	97.2
28.64	97.8	23.35	94.2	25.32	97.7
30.52	98.7	23.76	94.6	26.14	98.8
32.18	99.1	24.26	95.3	27.02	100.0
35.76	100.0	25.61	96.8		
		26.80	97.4		
		27.63	98.6		
		28.59	99.1		
		30.28	100.0		

TABLE IV

PERCENTAGE MOISTURE CONTENT OF LONGLEAF PINE HEART-WOOD SHAVINGS AT VARIOUS ATMOSPHERIC HUMIDITIES AND AT 25° C.

Samples of .51 specific gravity		Samples of .70 specific gravity		Samples of .75–.80 specific gravity		Resinous samples of .86–.94 specific gravity		
I	II	III	IV	V	VI	VII	VIII	IX
Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Moisture in shavings (per cent)	Relative humidity of chamber (per cent)	Per cent resin
3.89	10.6	3.68	9.8	4.12	11.8	6.25	23.1	19.3
4.48	12.6	5.0	15.0	5.62	18.6	7.24	31.2	17.1
5.32	17.6	5.88	20.0	7.14	26.6	7.9	38.3	18.4
6.78	26.0	7.14	28.2	7.16	29.4	9.42	51.6	16.4
7.82	31.6	7.64	33.0	7.8	34.8	9.36	55.4	19.3
8.84	46.6	8.25	40.0	8.88	49.6	9.71	58.7	19.3
10.08	54.8	8.62	42.2	9.87	53.0	10.58	58.7	18.4
11.06	59.8	9.28	48.2	10.21	57.6	10.27	60.8	17.1
12.2	66.4	9.31	50.0	10.68	61.2	11.28	64.4	16.4
13.8	74.4	10.78	60.0	11.28	62.5	11.76	66.0	16.4
15.52	81.4	11.64	63.6	11.72	65.1	12.26	68.7	18.4
17.10	85.4	12.72	70.0	13.38	72.9	12.2	70.8	16.4
20.10	90.8	16.22	83.8	14.27	76.6	12.81	71.7	17.1
21.78	93.4	17.4	86.8	18.54	88.3	13.02	74.3	18.9
23.68	95.6	19.21	89.4	19.71	90.7	13.94	78.0	17.1
25.1	96.6	22.79	94.6	20.86	92.1	14.31	78.7	16.4
26.62	97.4	24.36	96.51	23.27	95.6	14.82	82.4	19.3
27.8	98.0	26.11	98.	24.01	96.5	15.13	84.7	19.3
30.32	99.0	27.57	99.2	25.24	97.9	16.08	86.9	17.1
33.2	100.0	29.1	100.0	26.11	99.1	17.0	90.3	19.0
				26.89	100.0	16.75	91.5	16.4
						18.48	93.5	19.0
						17.41	93.8	19.3
						18.74	95.1	19.0
						19.66	95.3	16.4
						20.14	97.2	18.4
						20.15	99.1	18.4
						21.12	100.0	18.4

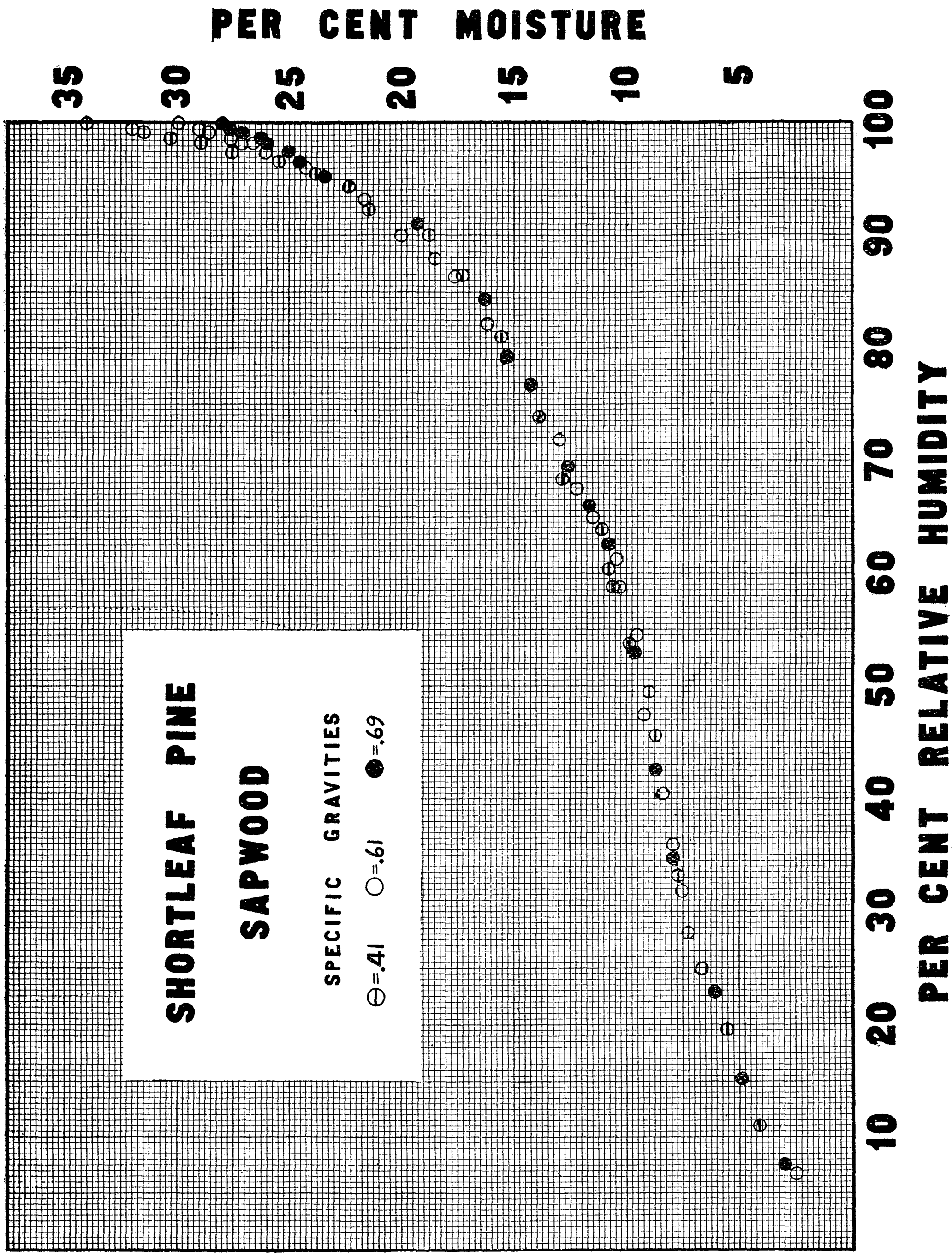

Fig. 1. Curve showing the moisture content of the sap-wood of shortleaf pine (*Pinus echinata*) at various atmospheric humidities and at 25° C.

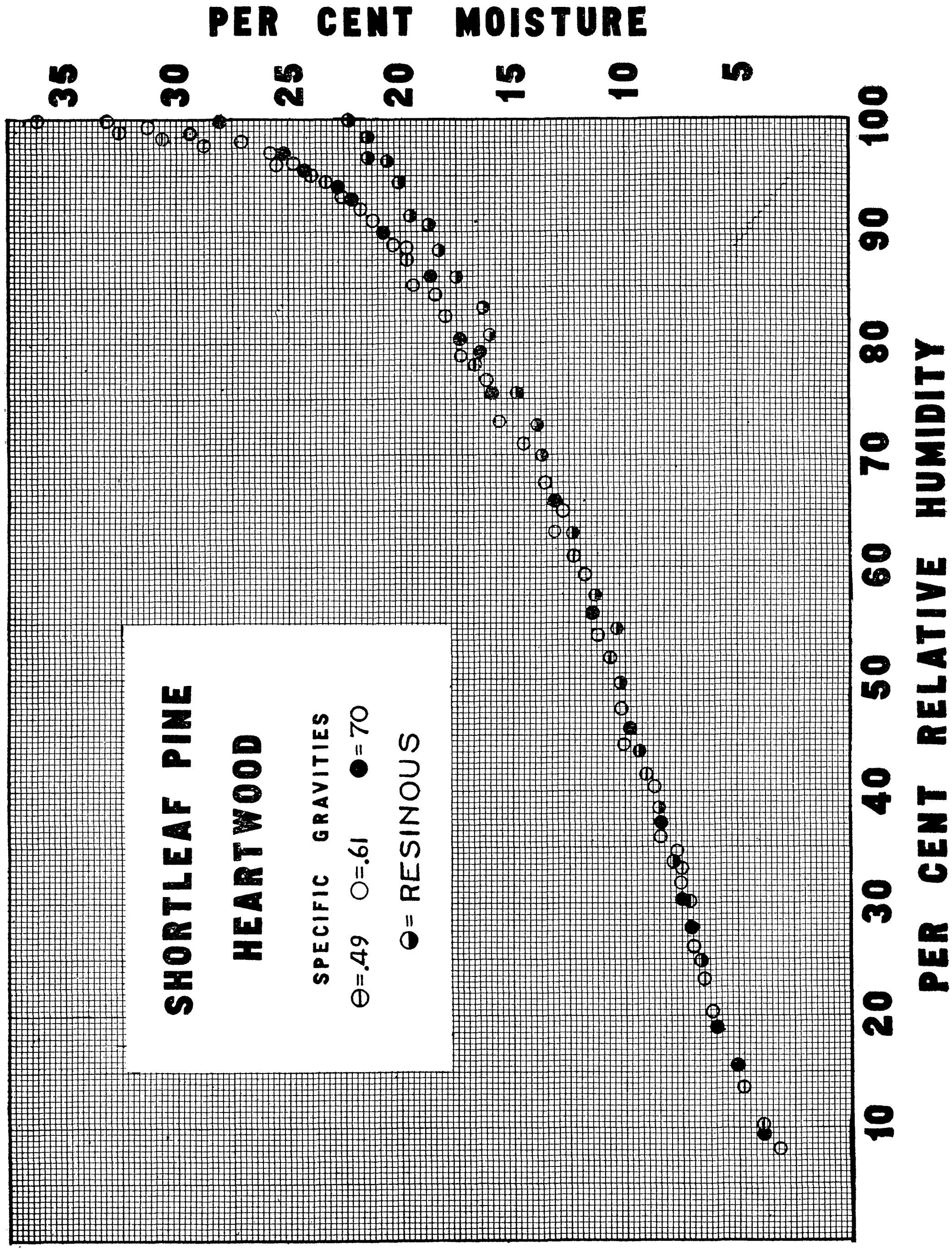

Fig. 2. Curve showing the moisture content of the heart-wood of shortleaf pine (*Pinus echinata*) at various atmospheric humidities and at 25° C.

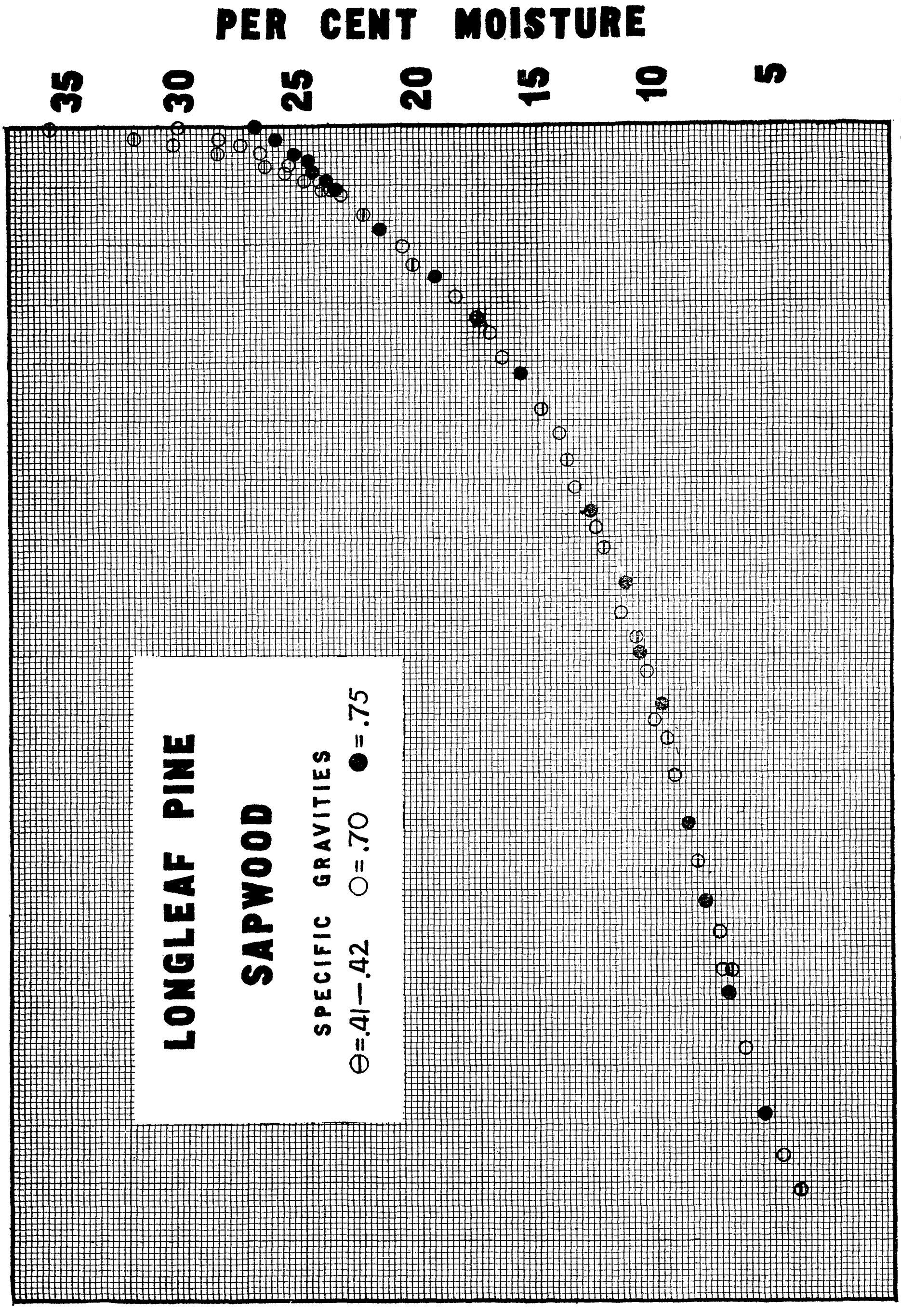

Fig. 3. Curve showing the moisture content of the sap-wood of longleaf pine (*Pinus palustris*) at various atmospheric humidities and at 25° C.

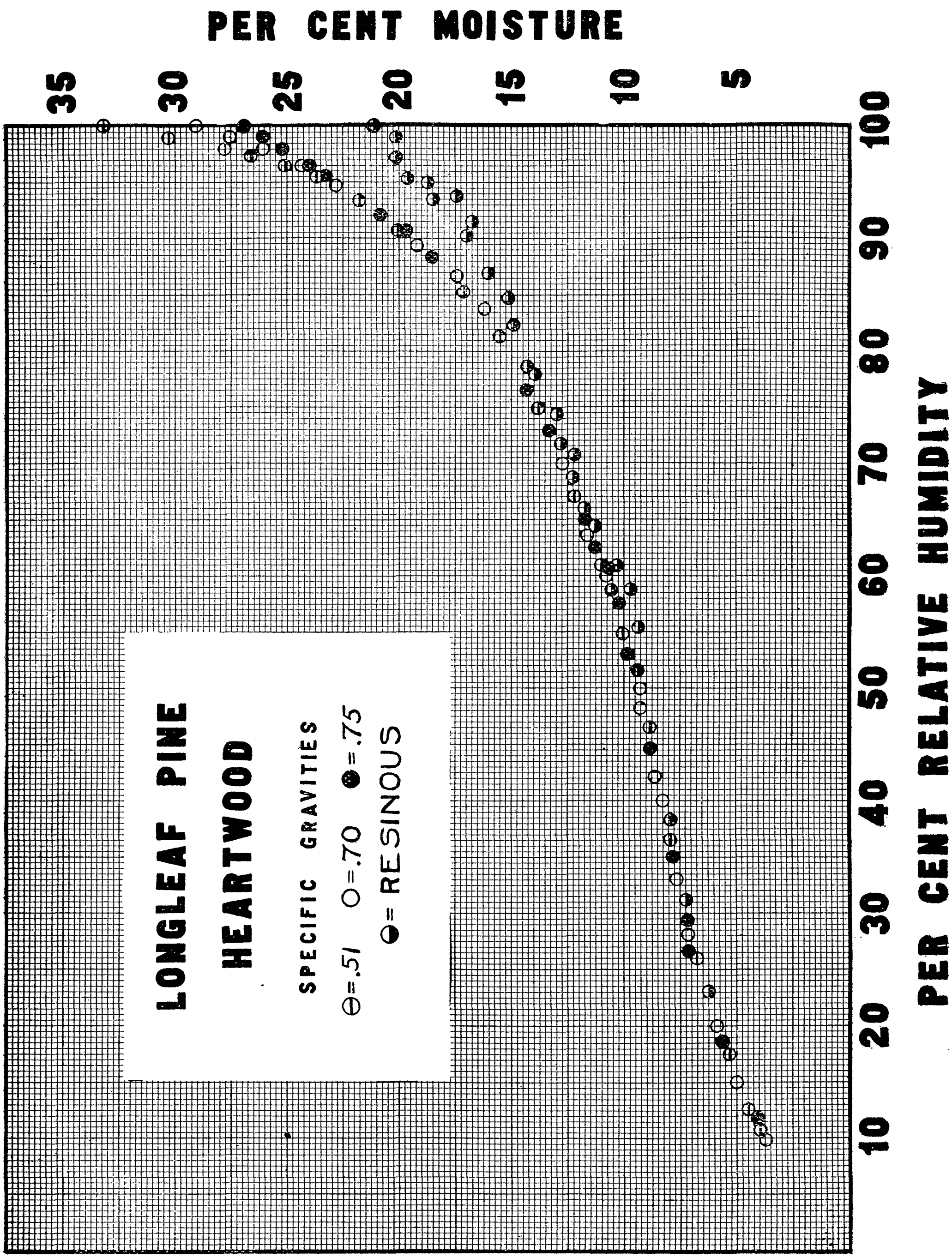

Fig. 4. Curve showing the moisture content of the heart-wood of longleaf pine (*Pinus palustris*) at various atmospheric humidities and at 25° C.

absorption of moisture by certain morphological and mechanical properties of the woody tissues which vary with the different species of wood. This variation in morphological and mechanical characters in the wood of different species will account for the slight differences in moisture content at the fibre-saturation point of shortleaf and longleaf specimens. The moisture content at the so-called fibre saturation point of the four curves is approximately as follows: shortleaf pine sap-wood, 24.25 per cent, heart-wood, 24.5 per cent, and longleaf pine sap-wood, 23.75 per cent, and the heart-wood, 23.25 per cent.

In timber-testing laboratories the fibre-saturation point of wood has been determined by means of strength tests, and has been defined by Tiemann ('07) as "the degree of moisture at which maximum absorption by the cell walls is reached." After this point is reached added moisture does not lessen the strength. Beginning with the dry conditions, with the increase of moisture the strength falls off very rapidly at first, then more slowly as the fibre-saturation point is reached, and here it abruptly ceases to decrease. This abrupt break in the moisture-strength relation represents the fibre-saturation point. The moisture per cent at fibre-saturation for longleaf pine as determined by Tiemann ('07) by compression tests on small specimens averaged 25 per cent, with a maximum at 26 per cent and a minimum at 24 per cent. This is not far removed from the moisture content at which the curves representing the three different specific gravities of longleaf pine diverge in figs. 1 and 2.

If this divergence of the moisture-humidity curve represents the fibre-saturation point the appreciable increase in moisture up to 100 per cent humidity must be moisture in the form of a surface film; that is, the fibre-saturation point is the point where absorption or imbibition by the fibre is replaced by a surface phenomenon, adsorption. In a unit weight of wood fibre the thin-walled, large-lumened cells, having a lower specific gravity than the heavy-walled, small-lumened cells, present a much greater surface than the latter. If the greater concave curvature of the smaller-lumened cells has any tendency to thicken the surface film in proportion to that adsorbed by those having less curvature, the difference in the total moisture created in this way evidently is not great enough to overcome the difference resulting from the difference in surface.

This relation of the moisture content of wood at various relative humidities has been demonstrated for other woods by workers at the United States Forest Products Laboratory located at Madison, Wisconsin. This work is reported in "Wood in Aircraft Construction" (1919) which was prepared by the above-mentioned laboratory for the United States Navy Department. The five woods worked with were Sitka spruce, black walnut, white oak, yellow birch, and ash, and the maximum moisture content at 100 per cent humidity ranged from about 29.5 to 30.2 per cent for Sitka spruce to about 36.7 per cent for ash. A report by Pfeiffer on the physical properties of several Javanese woods includes a study of their moisture contents at various atmospheric humidities. The maximum moisture contents of the various woods at 100 per cent humidity were as follows: *Tectona grandis* (teak wood), 21 per cent; *Ensideroxylon Zwageri*, 22 per cent; *Shorea* sp., 24 per cent; *Dipterocarpus* sp., 23 per cent; *Shorea* sp., 30 per cent, and *Alstonia* sp., 25 per cent. The specific gravities of these woods were .64, 1.04, .88, .64, .41, and .34, respectively. Although the order of increase in maximum moisture content in these Javanese woods is not in exactly the same order as the decrease in their specific gravities, there is a tendency in that direction. Of course, a direct relation throughout could not be expected because of the great differences in morphological and physical structures between various species.

RESIN CONTENT IN RELATION TO MOISTURE ABSORPTION

The data on this subject as presented in tables II and IV and illustrated graphically in the curves shown in figs. 2 and 4 are self-explanatory and for the most part need no discussion. However, there are a few points of interest which might be discussed briefly. In the lower part of the curves, where the relative humidity is less than 50 per cent, the points representing the highly resinous samples of wood show no deviation from the moisture curves of those samples of wood containing less than 5 per cent resin. Above 50 per cent humidity, however, there is a gradual deviation of the curve representing highly resinous specimens. This moisture curve is lower than that representing specimens containing less than 5 per cent resin. This illustrates the fact that resin actually has a water-proof-

ing effect upon the wood containing it, and that this water-proofing effect is considerable as the fibre-saturation point is approached. In the shortleaf heart-wood at a relative humidity of 95 per cent the moisture absorption was decreased 15.6 per cent by 17.6 per cent resin, and at 100 per cent humidity the minimum moisture decrease was 20.8 per cent, and the average decrease was 31.5 per cent brought about by 17.6 per cent resin. In the longleaf pine heart-wood at a relative humidity of 95 per cent a resin content of 16.4–19 per cent had a water-proofing effect of 17.4 per cent, while at 100 per cent humidity the water-proofing effect of 18.4 per cent resin averaged 29.3 per cent, with a minimum of 21.5 per cent reduction in the moisture content.

Undoubtedly, this water-proofing effect of resin has its influence upon the durability of structural timber placed under *very* humid conditions, providing the resin content is sufficient to lower the moisture content of the wood below that which is conducive to the growth of wood-decaying fungi. Although the resin does have some influence in this direction, it is probably not sufficient to be relied upon as a test of durability. More reliance could be put upon resin as an index of durability in timbers containing, for example, 12 to 15 per cent resin, providing there was any reason to believe that it was equally distributed throughout the timber. With such an equal distribution of the resin the water-proofing would undoubtedly be more effective at lower relative humidities. Not only this, but mechanical resistance of resin equally distributed would undoubtedly be a great factor in the inhibition of fungous growth in the wood. This, however, is not the case. The resin is deposited in streaks in wood so that there are portions relatively free from resin. These resin-free portions, having a hygroscopicity sufficient to take up considerable moisture under the right moisture conditions, become sources of weakness because of the inroads of wood-destroying fungi. Examples of such decay are often reported as very destructive to the ceilings and structural timbers under the highly humid conditions produced in the paper- and pulp-mills of the eastern states and Canada and the knitting-sheds of the cotton industries of New England. Further experimentation along this line is advisable. Some practical process of treating resinous lumber, possibly by modifying the kiln-drying

processes so as to distribute the resin more evenly, is a worthy project of investigation of this important problem in these industries.

SPORE GERMINATION ON WOOD

The spores of wood-destroying fungi exhibit a marked similarity with regard to their requirements for germination. Some of the factors which influence germination are proper temperature and proper amounts of acidity and moisture. As early as 1860 Hoffmann ('60) found that in a period of five days spores of *Polyporus versicolor* germinated in moist air, and in a period of six days spores of *P. squamosus* germinated better in moist air than in water. On the other hand, Falck ('09) says that the spores of *Lenzites* on wood germinate only when the wood has been thoroughly saturated by rains.

To determine more accurately the relation of moisture to the germination of spores of a wood-destroying fungus the following experiments were conducted, using the spores of *Lenzites saepiaria*. The spores of this fungus were obtained from rejuvenated fruiting bodies as described in a previous paper (Zeller, '16). The spores were allowed to drop from the fruiting bodies directly upon thin shavings of shortleaf pine (*Pinus echinata*) sap-wood, or were caught in Petri dishes and transferred to the shavings in a loop of sterile distilled water and allowed to dry rapidly in the air.[1]

The shavings upon which the spores were deposited were clamped in a small device which may be described as follows: Two pieces of sheet celluloid, about the size of a microscope slide, were riveted together at one end by means of a paper rivet, and a round hole about 1 cm. in diameter was cut through the middle of the two celluloid slides. The pieces of celluloid were bent apart while a shaving to which the spores were adhering was slipped between, the other end of the pieces of celluloid being clamped together by means of a paper clip. The shaving is thus held so that it covers the hole in the middle of the device

[1] A decoction from 60 gms. of shavings of shortleaf-pine sap-wood was prepared by steaming the shavings in a reflux with 10 cc. of distilled water. This decoction tested P_H 4.2, so that the actual active acidity of the shavings probably was not above P_H 3.8. This would be well toward the optimum acidity (P_H 3.1) for the germination of the spores of *Lenzites saepiaria* as reported by Webb ('19).

and is exposed to the air from both sides. These devices were numbered, and after the chamber of the humidor, described elsewhere in this paper, had come to a constant humidity, one of them was lowered into the chamber through the opening in the top. By means of the lever it was hung on a wire without opening the chamber. In this way spores were exposed to the atmospheric conditions of the chamber without coming in contact with any other object. A new shaving was added to the chamber on 12 successive days. All were removed at one time, examined under the microscope, and the percentage of germination estimated on the basis of the total number of spores in a unit field. In table v the percentages of germination

TABLE V

RELATION OF THE GERMINATION OF THE SPORES OF LENZITES SAEPIARIA TO THE RELATIVE HUMIDITY OF THE ATMOSPHERE AT 25° C.

Germination period (days)	Per cent germination (averages)	Per cent relative humidity	Germination period (days)	Per cent germination (averages)	Per cent relative humidity
10	1.5	63.0	5	76.0	96.5
10	2.5	65.0	5	85.5	98.5
10	3.5	67.4	5	100.0	99.0
10	2.5	72.5	5	100.0	98.0
7	4.0	78.5	5	95.0	98.0
7	7.5	82.5	6	57.5	96.0
7	5.5	85.5	6	80.0	98.0
7	10.0	89.8	6	87.5	98.0
5	20.5	90.5	6	92.0	99.0
5	25.5	92.5	6	96.5	99.0
5	70.0	95.5	6	100.0	98.5

are the averages of three or four counts. In fig. 5 the relation of spore germination to relative humidity is presented graphically. This curve indicates that until the fibre-saturation point is reached the percentage of spore germination is very low, but as soon as the humidity of the air is sufficiently high to supply free

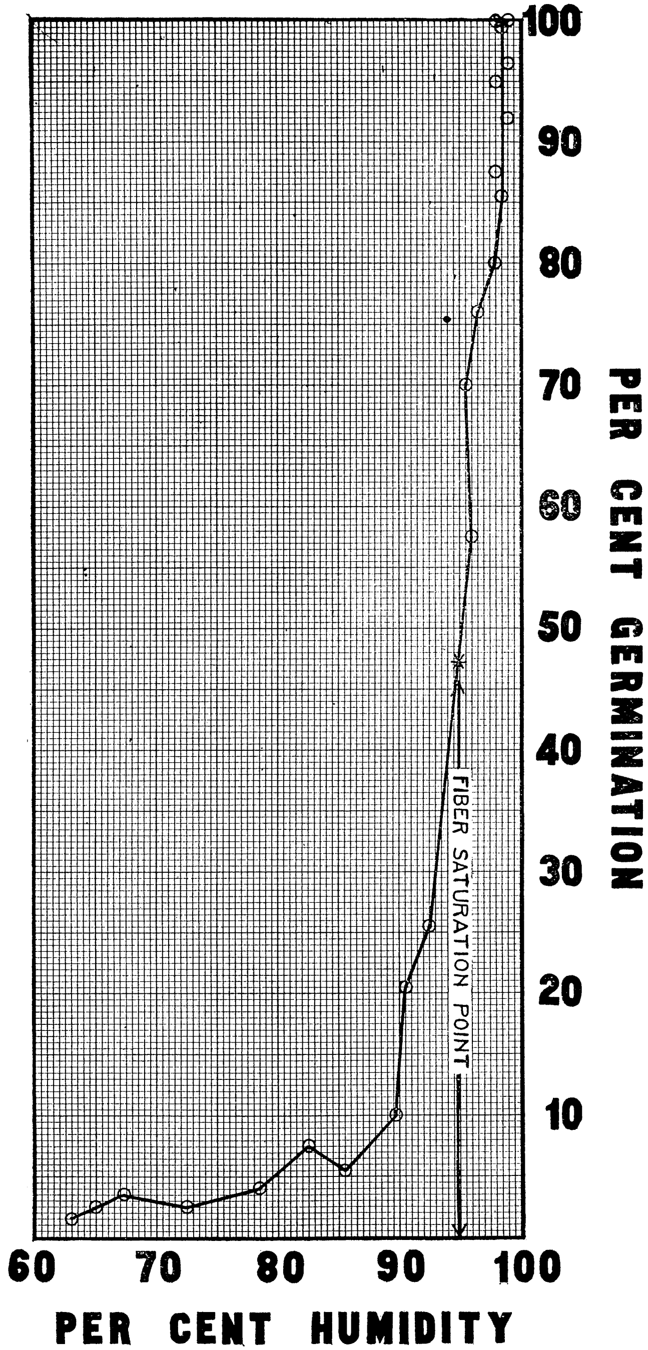

Fig. 5. Curve showing the percentage of germination of spores of *Lenzites saepiaria* on shavings of the sap-wood of *Pinus echinata* at various atmospheric humidities and at 25° C.

water as a film on the wood surface the spores of *Lenzites saepiaria* show a high percentage of germination.

By growing *Ceratostomella coerulea* upon blocks of pine sapwood Münch ('09) found that free-water on the wood was necessary to sustain growth. Growth is maintained if fibre-saturation is maintained, but if the water of imbibition falls below the saturation point the wood seems to demand water at the expense of the mycelium. Although true for *Ceratostomella* this very probably is not true for the mycelium of such fungi as *Lenzites saepiaria, Merulius lacrymans,* or *Coniophora cerebella,* which after becoming well established, seem to maintain a water supply from some unknown source. This is especially the case with *Merulius lacrymans.* Wehmer ('14) found that this fungus would not grow on blocks of wood in ordinary cellar humidity unless the blocks were first saturated with water. After the growth was well established, however, the water content of the wood was maintained by the fungus above that in sound wood under the same conditions.

It would seem then that for the germination of the spores and the establishment of the mycelium of wood-destroying fungi, the wood must contain enough moisture to saturate the wood fibre. This becomes a serious problem then in such buildings as paper- and pulp-mills and knitting factories where high humidities are maintained. If the temperatures fluctuate across the dew-point, the moisture content of any exposed woodwork is maintained up to fibre-saturation and the wood is sure to decay unless some method of treatment of the timbers is possible.

Summary

In this paper are reported the results of experiments (1) showing the moisture content of wood at various atmospheric humidities and at 25° C. Curves are presented to illustrate this relation for the sap- and heart-wood of both longleaf and shortleaf pine.

(2) By testing the moisture content of any one species of wood samples having various specific gravities at the various humidities it is possible to approximate the fibre-saturation point of the wood.

(3) The moisture-humidity curves of highly resinous samples

of wood illustrate the water-proofing effect of resin on the wood, especially above 50 per cent humidity. It is believed that resin cannot be relied upon as an indication of the durability of lumber although present in amounts as high as 12–15 per cent, for it is seldom equally distributed in the wood. The regions of low resin content are sources of weakness if wood-destroying fungi gain access to them under favorable moisture conditions.

(4) The germination of the spores of *Lenzites saepiaria* on wood shavings was accomplished at various relative humidities ranging from 63 to 100 per cent. The germination curve illustrates the fact that spore germination is exceedingly accelerated when the atmospheric humidity is high enough to maintain fibre saturation of the wood.

(5) A humidor for maintaining constant humidity and temperature is described. It is provided with (1) a dew-point apparatus for the determination of humidity, and (2) a weighing device so that the samples can be weighed without opening the humidity chamber.

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Description of Plate

PLATE 1

Fig. 1. A general view of the humidor as described on page 53, with the balances in place and both doors open.

Fig. 2. The interior of the humidor showing the baskets containing the samples of shavings, one basket hanging on the balance and the Milliken dew-point apparatus in the central foreground.

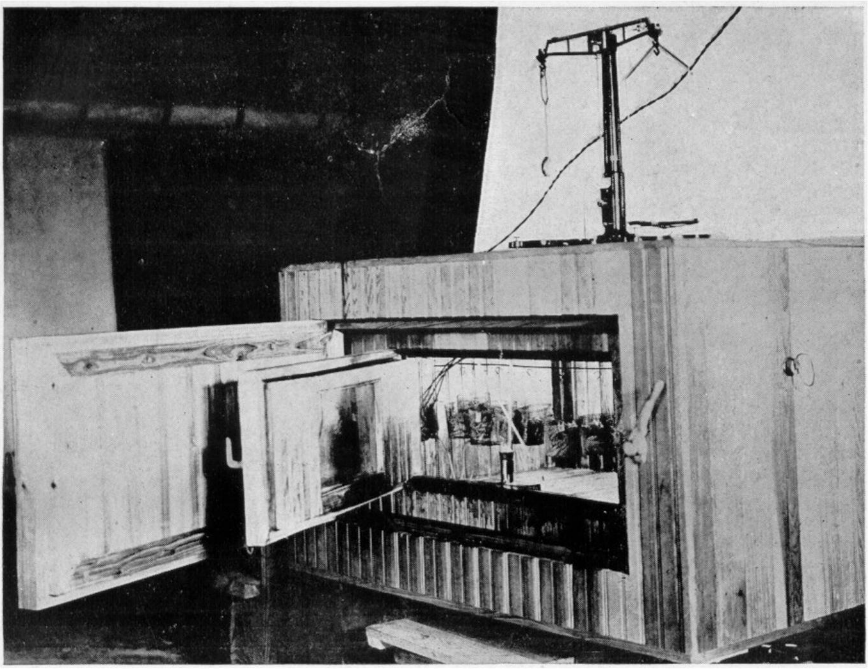

FIG. 1

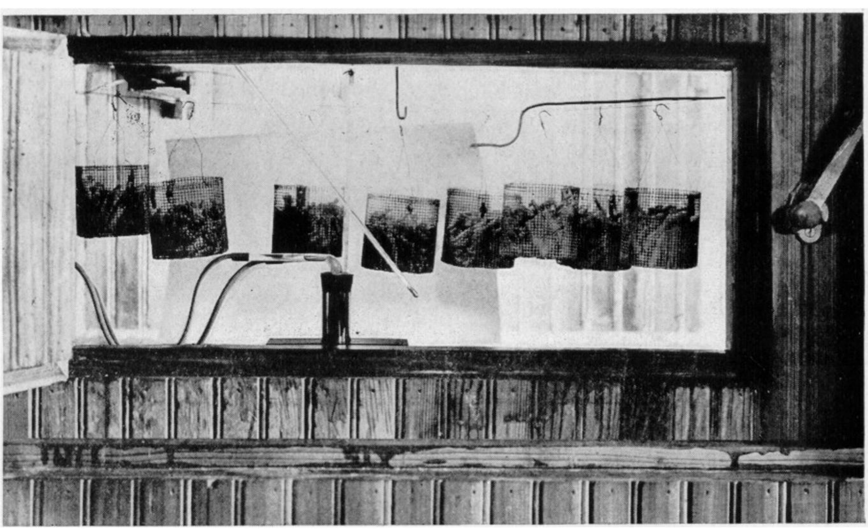

FIG. 2

ZELLER, IMBIBITION BY WOOD, AND SPORE GERMINATION